Distributed Image Compression Architecture over Wireless Multimedia Sensor Networks based on IoT

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ABSTRACT:
In a wireless multimedia sensor network (WMSN), the minimization of network energy consumption is a crucial task not just for scalar data but also for multimedia. In this network, a camera node (CN) captures images and transmits them to a base station (BS). Several sensor nodes (SNs) are also placed throughout the network to facilitate the proper functioning of the network. Transmitting an image requires a large amount of energy due to the image size and distance; however, SNs are resource constrained. Image compression is used to scale down image size; however, it is accompanied by a computational complexity trade-off. Moreover, direct image transmission to a BS requires more energy. Thus, in this paper, we present a distributed image compression architecture over WMSN for prolonging the overall network lifetime (at high throughput). However, such a collaboration is usually not feasible, and compression has to be performed independently at each node. The problem of compressing correlated information in a distributed fashion is known as distributed source coding.

Keywords: WMSN, Camera Node (CN), Base Station (BS), Sensor Node (SN).

I INTRODUCTION

The Internet plays a vital role in communication by connecting people around the world through millions of networking devices. The availability of advanced low-cost devices has led to the development of the Internet of Things (IoT). The Internet is moving toward the IoT and Cloud Computing, including Big Data, which has become the most important global technology platform for the future. Typically, the IoT is composed of smart things (or smart devices), which have the ability to detect (sense) or cooperate (communicate) with a physical environment and other devices over large- scale and easy-to-deliver channels (wireless) with optional pre-processing or control those devices to deliver some particular tasks (processing).
Our scheme consists of three subtasks:

a. determining the optimal camera radius for prolonging the CN lifetime,
b. distributing image compression tasks among the potential SNs to balance the energy,
c. finally, adopting a multi hop hierarchical routing scheme to reduce the long-distance transmission energy.

The wireless sensor network (WSN) is another key part of the IoT, which is used in many fields, such traffic, military, industry, and environmental monitoring and control. In general, a single wireless sensor node (SN) consists of a readily available and inexpensive sensor, a data processor, memory, a receiver/transceiver, and power units for capturing scalar data, such as temperature, pressure, humidity, velocity acceleration, and location. Recently, information has been changing from scalar data to multimedia data, such as image, video, and audio data.

A WMSN extends a typical WSN by adding multimedia services and devices, such as a Complementary Metal Oxide Semiconductor (CMOS) camera and a microphone, to capture images, video, or audio, which allows the device to retrieve not only scalar data but also multimedia streams.

Although many image compression techniques have been proposed, most are very complicated and have high resource requirements; thus, they cannot perform well in a resource- constrained WMSN. If the image compression prcess relies on a single SN, this sensor node may quickly run out of energy.

II IOT (INTERNET OF THINGS)

IoT is the networking of physical objects that contain electronics embedded within their architecture in order to communicate and sense interactions amongst each other or with respect to the external environment. In the upcoming years, IoT-based technology will offer advanced levels of services and practically change the way people lead their daily lives. Advancements in medicine, power, gene therapies, agriculture, smart cities, and smart homes are just a few of the categorical examples where IoT is strongly established.

Four Key Components of IOT

- Device or sensor
- Connectivity
- Data processing
- Interface

2.1. Sensor

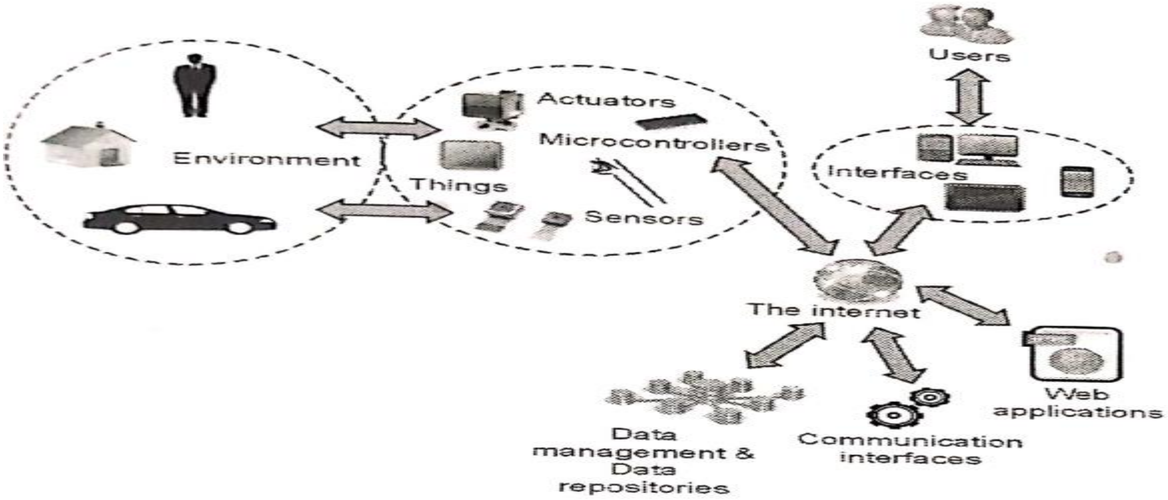
Sensors: Sensors are the major part of any IoT application. It is a physical device that measures and detects certain physical quantities and converts it into signal which can be provided as an input to processing or control unit for analysis purpose.

2.2. Sensor Node

A single wireless sensor node (SN) consists of a readily available and inexpensive sensor, a data processor, memory, a receiver/transceiver, and power units for capturing scalar data, such as temperature, pressure, humidity, velocity,acceleration, and location

There are two ways of building IoT:

- Form a separate internet work including only physical objects.
- Make the Internet ever more expansive, but this requires hard-core technologies such as rigorous cloud computing and rapid big data storage (expensive).



2.3. Camera Node (CN)

camera nodes could communicate with each other, it would be possible to develop algorithms that would compress the data and so reduce bandwidth requirements.

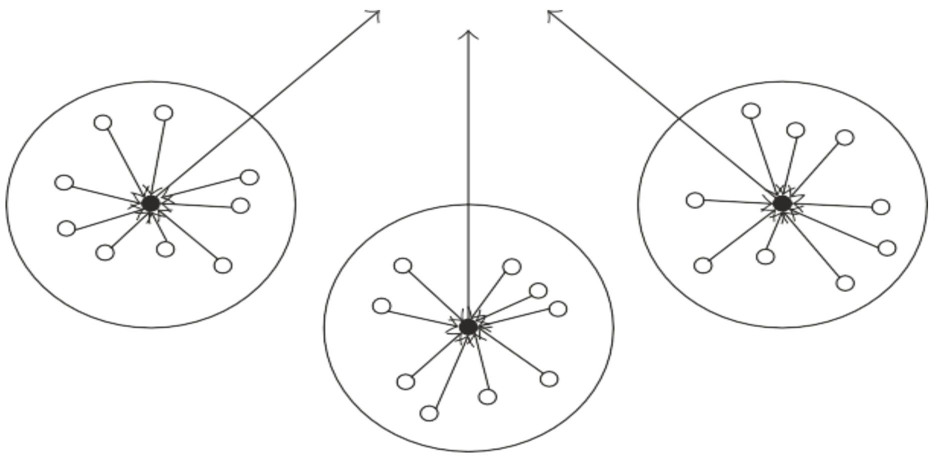
2.4.Base Station(BS)

A base station serves as a central connection point for a wireless device to communicate. It further connects the device to other networks or devices, usually through dedicated high bandwidth wire or fiber optic connections.

2.5. Complementary Metal-Oxide Semiconductor (CMOS)

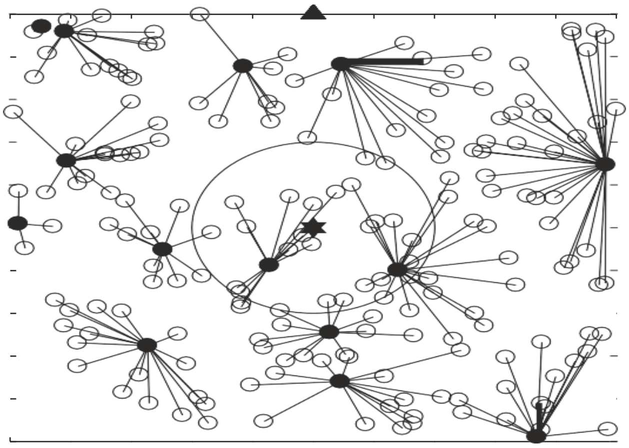
A complementary metal-oxide semiconductor (CMOS) is the **semiconductor technology used in most of today's integrated circuits (ICs), also known as chips or microchips**. CMOS transistors are based on metal-oxide semiconductor field-effect transistor (MOSFET) technology.

Base Station



- Normal node
- Cluster head

(a) Transmission cluster (WSN)



- Camera node Cluster head
- Normal node Base station

(b) Camera cluster (WSMN)

FIGURE: Sensor node deployment

III METHODS

3.1.EEDIC(Energy-Efficient Distributed Image Compression)

The performance of our proposed architecture is evaluated with respect to various metrics, in comparison with an energy-efficient distributed image compression scheme in resource-constrained multi- hop wireless networks.

3.2. LEACH(Low- Energy Adaptive Clustering)

Many researchers have applied LEACH in WSNs. How-ever, LEACH does not consider the effects of multimedia data in WMSNs, such as images with huge size and other considerations, such as computing power and space con- straints.

3.3.Discrete Cosine Transform (DCT)

The DCT is **a technique allowing the conversion of a signal into elementary frequency components**. More in particular, in the DCT the input signal is represented as a linear combination of weighted basis functions that are related to its frequency components.

$\hat{f}[2k]=\lambda k\Sigma n=0N/2-1(f[n]+f[N-1-n])\cos[\pi kN/2(n+12)]$,

$\hat{f}[2k+1]=\Sigma n=0N/2-1(f[n]+f[N-1-n])\cos[\pi k(k+1/2)N/2(n+12)]$.

3.4. Discrete Wavelet Transform (DWT)

Discrete Wavelet Transform is a technique to transform image pixels into wavelets, which are then used for wavelet-based compression and coding.

$$f(x)=\frac{1}{\sqrt{M}}\sum_{k}W_{\varphi}(j_0,k)\varphi_{j_0,k}(x)+\frac{1}{\sqrt{M}}\sum_{j=j_0}^{\infty}\sum_{k}W_{\psi}(j,k)\psi_{j,k}(x).$$

IV RELATED WORK

Typically,a WSN requires a routing protocol to minimize theenergy consumption of data transmission. As a clustering-based approach, low-energy adaptive clustering hierarchy (LEACH) is a well-known routing protocol in WSNs. This protocol is an adaptive and self-organizing clustering proto-col that generates a random value to select a CH in rotation among SNs.

JPEG2000 is another well-known DWT-based algorithm with the key advantage of providing a better image compression ratio, better image quality, and higher resistance to data transmission error and decoding error; therefore, high-complexity image transmission is not required for prolonging the network lifetime in the context of a WSN or WMSN.

JPEG2000 has been adopted in WMSNs in some works;for example, Zuo et al. [19] presented a two-hop clustered image transmission scheme that was based on traditional LEACH. They divided the clusters into two categories: camera clusters and normal clusters. The camera cluster forms during the first round; a fixed camera radius is carefully considered to ensure that the camera cluster hasan adequate number of nodes to receive the image fromthe CN and then compress the image before sending it tothe BS via the CH. At the beginning, the fixed optimized camera cluster radius is determined based on transmission radius adjustment. If the camera radius is too small, there would not be an adequate number of sensor nodes for the camera cluster, whereas if the radius is too large, the image transmission may require more energy than the image com-pression. In addition, conflicts between camera clusters can occur.

After completing the 1D wavelet transform, the SNs in this group send the intermediate result back to CH_3 for the other 1D wavelet transform. CH_3 sends the level 2 data to CH_4 for quantization. Then, CH_4 sends the level 2 data to a single sensor node, namely, SN_{4i}, for quantization, whereasthe other SNs in this cluster are awakened. The number of levels depends on the compression target. After quantization, SN_{4i} sends the data to CH_5. Then, CH_5 divides the quantizedsubbands into multiple smaller code blocks of equal size andsends them to a set of nodes, namely, SN_{5i} (SN_{53}, SN_{52}, SN_{53}, and SN_{54}), for independent code block entropy encoding to produce compressed bitstreams.

FLS with two input variables: the distance to the BS and the residual energy. A broadcasting message is sent by each tentative CH to compete with the other tentative CHs locally. If a tentative CH receives a broadcasting message from another tentative CH that has higher energy than its remaining energy within its competitive range, the tentativeCH broadcasts the quit message; however, if the tentative CHreceives broadcasting messages from tentative CHs whose energies are lower than its remaining energy, it becomes the CH. Compared to other unequal and equal clustering algorithms, this algorithm can perform better; unfortunately,it may cause imbalanced energy consumption of SNs in the WSN if the randomly selected CHs have lower remaining energy.

V SYSTEM MODEL

5.1 Network Model

In this paper, we make the followingnetwork assumptions:

1. All sensor nodes (SN) are deployed randomly and uniformly in a targeted area ($M \times M$).
2. The network is composed of two types of SNs: camerasensor nodes or camera nodes (CNs) and typical sensor nodes or normal nodes (NNs).
3. The number of the CNs is far less than the number ofNNs.

5.2. Energy Consumption Model

While transmitting and receiving data, that is, packets that are based on the IEEE 802.15c framework, in WSNs or WMSNs, each SN consumes energy. The energy consumption is based on the size of the packet and the distance between sender and receiver. This paper adapts a simplified model that is used in LEACH for the communication energy consumption model.

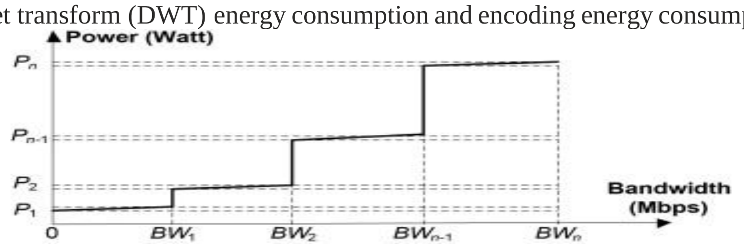
E(T)=∫0TPower(t)dt

5.3 Router Energy Consumption Model

This defines the energy consumption of a router to be the accumulation of the energy consumption when the router is booting, working, and halting.

$$E = E_{boot} + E_{work} + E_{halt}$$

JPEG2000, which is a wavelet-based image compressionscheme, is used in this study. The energy consumption is divided into two parts: discrete wavelet transform (DWT) energy consumption and encoding energy consumption.



5.4 Definition And Notation

Before proceeding to the pro- posed algorithm, the following definitions and notations arepresented.

Definition 1 (sensor nodes). The wireless sensor networkconsists of N sensor nodes. We denote SN = {$SN_1, SN_2, SN_3, \ldots, SN_N$}, where |SN| = N and SN_i represents the ith sensor node.Definition 2 (competitive radius). The competitive radius of acamera node is determined by an appropriate camera clustersize. The competitive radius of camera node CN_i is defined as R_{CN_i} and should satisfy

$$R_{CN_i} \le R_c.$$

Definition 3 (communication cluster). For energy efficiency,all SNs are grouped into sets, which are called clusters. A setof SNs consists of many SNs, of which only one is elected to be the cluster head (CH), while the rest are just member nodes. Member nodes send the data to their CH, which thenforwards the data to the next destination.

Definition 4 (camera cluster). In a camera cluster, there is one camera node CN and its neighboring nodes NB_{CN}. Thiscluster is formed to share the processing and transmission task of the camera node. The camera node acts as the clusterhead of the camera cluster.

Definition 5 (image compression cluster). The image com- pression cluster is formed during data transmission. This cluster is used to compress the image before transmitting it to the BS. The highest-energy node in the camera cluster is selected to be the cluster head of image compression clusterICH. The neighboring nodes of image compression cluster head NB_{ICH} are members of the image compression cluster.

VI ALGORITHM

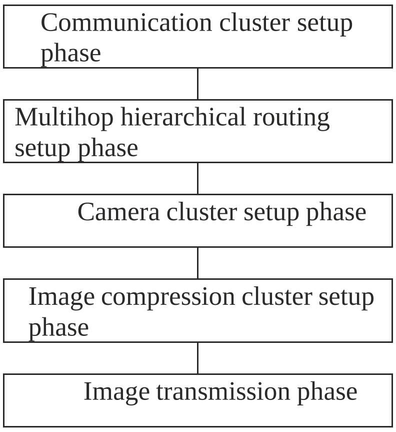
1. CH-Msg (ID): this message is sent by the communi-cation CH to its neighbors to announce itself as a CHand contains only the CH's ID. CL-Join-Request-Msg (CH ID, ID): this message is sent by neighboring nodes of the communication CH to request to join the communication cluster. The message includes the ID of the CH and the ID of theSN that wants to join the cluster.
2. Level-Msg (ID, routing level): the BS and communica- tion CHs broadcast this message, which contains theirIDs and routing level information, to their neighborsto build a hierarchical routing structure.
3. Level-Request-Msg (ID): during a specific time, com-munication CHs, which do not receive any Level- Msg, broadcast this message to their neighboring SNsto request routing level information. The ID of the requesting CH is stored in this message.
4. Level-Reply-Msg (ID, routing level): after receiving aLevel-Request-Msg from the requesting communica-tion CH, the SN replies with a Level-Request-Msg, which contains its ID and routing level information.
5. Cam-Msg (ID, cam energy, node degree): the CN sends a Cam-Msg, which contains its ID, remaining energy, and node degree, to its neighboring nodes toform a camera cluster.
6. Cam-Join-Request-Msg (ID, energy): this message issent by a neighboring node of the CN to join the camera cluster. The message contains the ID and remaining energy of the neighboring node of the CN.
7. Relay-Msg (ID): this message is sent by the source SN to its neighbors to find the relay node and contains theID of the source node.

8. Relay-Reply-Msg (ID, routing level, energy): after re-ceiving Relay-Msg, the neighboring nodes of thesource node send this message back to source node. This message contains their IDs, routing level infor-mation, and remaining energies.

VII MULTIHOP WIRELESSMULTIMEDIA SENSOR NETWORKS

7.1Communication Cluster Setup.

In our proposed archi- tecture, before proceeding to the other phases, the communication clusters are established. For the purpose of forwarding images to the BS, the WMSN is divided into many clusters, which are called communication clusters.



7. 2 Multihop Hierarchical Routing Setup

After the commu-nication cluster has been set up, the next step is the multihophierarchical routing setup phase. Here, a level of the hierar-chical routing information structure is constructed to offer better routing information for multihop communications.

if *round == 1* **then**
BS broadcasts *Level-Msg* containing *routing level = 1*.
if SN receives the broadcasting message **then**
if Message is *Level-Msg* **then**
if *routing level* of node != 0 **then**
if *routing level* of node > *routing level* within received message **then**
Update *routing level* of SN
if Node is CH **then**
routing level ← routing level + 1
Broadcast new *Level-Msg (ID, routing level)*
end if
end if
Else
Update *routing level* of SN with *routing level* within received message
end if
else if Message is *Level-Request-Msg* **then**
if *routing level* of node != 0 **then**
Send *Reply-Request-Msg (ID, routing level)* to the requested SN
end if
End

ALgoRITHM 1: Multihop hierarchical routing level setup

7.3 Camera Cluster Setup

The camera cluster consists of one CN, which acts as the CH of this cluster and nearby member nodes. Once communication cluster setup and multihierarchical routing setup are completed, the camera cluster setup phase is conducted. Since the energies of the member nodes are changing all the time, this phase mustbe implemented in every round in the network to ensurethat the camera cluster has enough member nodes for imageprocessing and transmission.

7.3.1 Fuzzy Logic System. Fuzzy logic or set, which was devel-oped by Zadeh [31], is an effective technique for improvingdecision-making in resource-constrained networks such as WSNs because FLS can reduce the resource consumption while maintaining effective performance and offering good solutions for many control problems by imitating the humanthought process.

if Node is CN **then**
if round==1 **then**
node degree = 0;
competitve radius = $RSSI_{max}$
else

node degree ← calculate node degree
competitive radius ← calculate competitive radius based on algorithm in Section 4.3.2
end

ALGORITHM 2: Fuzzy logic-based camera cluster setup

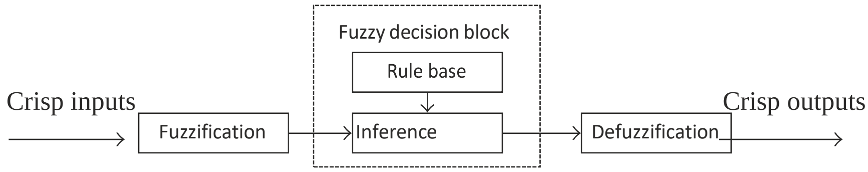


Figure: Basic block diagram of a fuzzy system

TABLE 1: Fuzzy rules of camera cluster radius

Camera node energy	Neighboring camera node	Node degree	Fuzzy cost
Low	Low	Low	Very high
Low	Low	Medium	Low
Low	Low	High	Very low
Low	Medium	Low	High
Low	Medium	Medium	Low
Low	Medium	High	Very low
Low	High	Low	High
Low	High	Medium	Low
Low	High	High	Very low
Medium	Low	Low	High
Medium	Low	Medium	Low
Medium	Low	High	Very low
Medium	Medium	Low	Rather high
Medium	Medium	Medium	Low
Medium	Medium	High	Very low
Medium	High	Low	Medium high
Medium	High	Medium	Low
Medium	High	High	Very low
High	Low	Low	Medium
High	Low	Medium	Low
High	Low	High	Very low
High	Medium	Low	Medium low
High	Medium	Medium	Low
High	Medium	High	Very low
High	High	Low	Rather low
High	High	Medium	Low
High	High	High	Very low

FIGURE: Discrete wavelet transform of a grayscale image.

7.4 Distributed JPEG2000 Compression

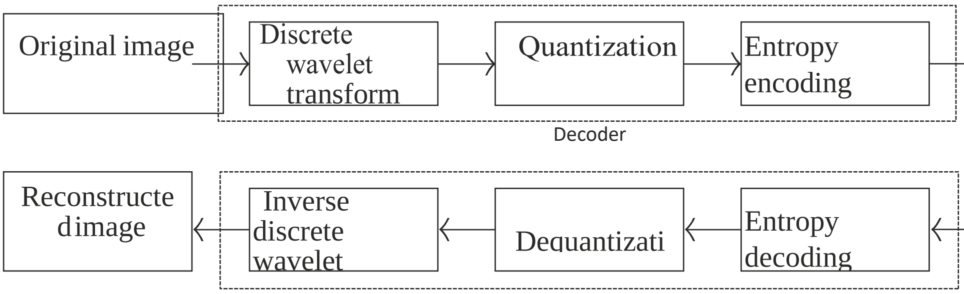


Figure: Flow Diagram of Distributed JPEG2000 Compression

CONCLUSIONS

A distributed image compression architectur (DICA) over WMSNs is proposed in this paper. Three main contributions have been discussed. First, the optimal camera cluster is determined by using FLS. Second, image compression tasksare distributed among SNs, which are close to each other within the image compression cluster to save energy. Lastly,multihop hierarchical routing has been developed to pre- serve and balance energy in the network. According tosimulation experiments, our algorithm can improve the energy consumption efficiency, on average, by 10%, 40%, and80% compared to 2HCIT, EEDIC, and LEACH, respectively, thereby prolonging the network lifetime and increasing the throughput compared to the above-discussed algorithms forboth sparse and dense networks.

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